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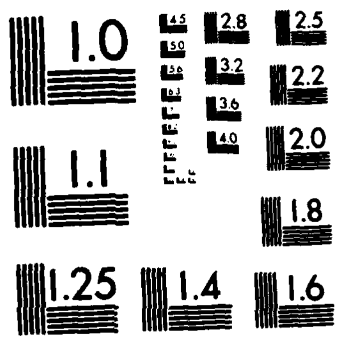

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COLD REGIONS TECHNICAL DIGEST No. 83-2, NOVEMBER 1983

USA Cold Regions Research and Engineering Laboratory
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Ice-blocked drainage: Problems and processes

Kevin L. Carey

Introduction

The northern winter brings numerous headaches for maintenance crews who work on streets and highways, railroads, airfields, and other public works. Among the causes of these headaches are drainage facilities that become blocked by ice. Many ice problems can be avoided by good drainage design. Maintenance personnel have made many worthwhile suggestions to designers, based on their winter experiences. But the winter problems remain at thousands of sites, and it is up to maintenance personnel to understand these problems so they can be in a better position to solve them.

Types of problems

Most problems caused by ice-blocked drainage arise in culverts, ditches and subsurface drains. Other problem spots are inlets and outlets, scupper drains and downspouts, small bridge openings, and flow-control structures. Basically, ice forms and obstructs water flow through the drainage facilities. If a drain gets completely blocked, water becomes ponded or is diverted to areas that were meant to be kept drained. Water and ice then interfere with the operation of the roadway, airfield, or other facility that the drainage serves. Other

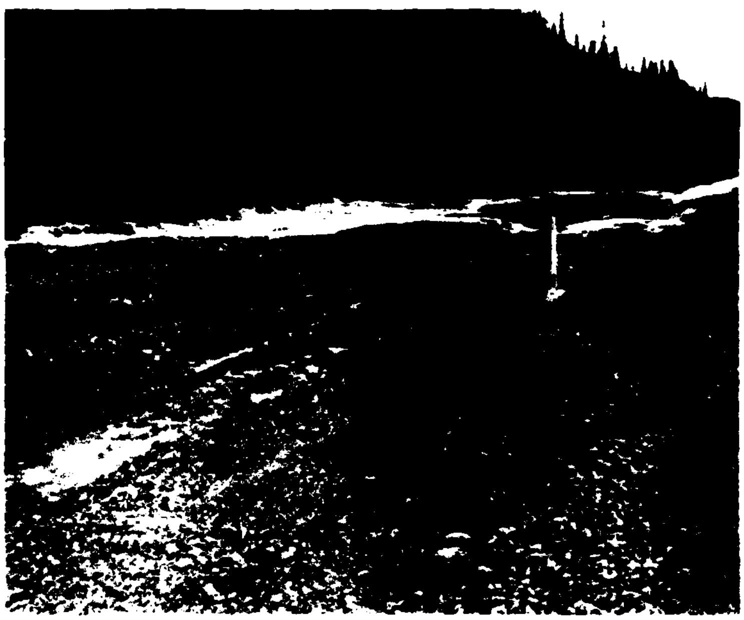
1. An ice-filled culvert being cleared by steam and hand tools in preparation for spring runoff.

results can include increases in the water level of streams and channels, raised water tables, saturated fills and embankments, and washouts.

Culverts. Ice formation inside a culvert reduces its cross section and thus its capacity. Depending on slope, flow rate, and inlet and outlet conditions, ice may build up evenly throughout a culvert, or it may form mainly at either the inlet or the outlet. In some cases ice begins building up in the channel upstream or downstream of a culvert, and slowly grows toward it. This is particularly true in the far north, where a form of ice build-up known as an "icing" spreads into culverts and often fills them completely (Fig. 1).

Ditches. Ice blockage in ditches leads to ponding and overflow. Ice can begin forming in ditch bottoms and steadily build up to higher levels (Fig. 2), or it may enter from the side of the ditch as a result of freezing backslope seepage (Fig. 3). Debris or heavy vegetation in a ditch that doesn't impede the flow in warm weather can cause ice build-up in winter. Depending on how severe the climate is, windblown or fallen snow can fill a ditch and contribute to ice build-up.

2. Ice formed in the bottom of a ditch in late fall. The ice level will rise as flow and freezing continue.



3. Seepage from the backslope has frozen and begun to fill this wide ditch with ice.

Usually snow acts as a good insulator, allowing water to seep or flow through it at the base of the ditch without freezing. But if the water reaches a spot in the ditch which is snow-free, ice can form quickly and may dam the flow.

Subsurface Drains. Subsurface drains are usually designed so that they don't get direct inflow from surface water. They are intended to drain underground seepage or groundwater. But ice blockage can happen in two ways. First, even though subdrains are supposed to be placed below the depth reached by frost, unusually deep frost may reach them and freeze the water inside. Even if this only happens in part of the drainage system (for example, under an area plowed clear of snow, allowing deeper frost), then seepage water will back up in the system upstream from the blockage. This can cause saturated soil and earth slumps or slides. The second and more common problem is to have ice block the outlets of a subsurface drainage system, where the drainage water first encounters low air temperatures. When this happens, the whole system becomes backed up with water.

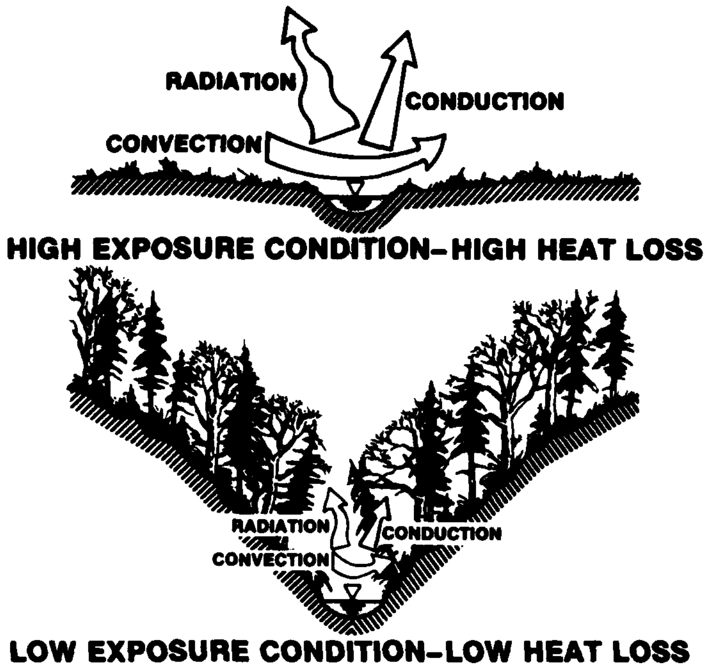
Ice-blockage processes

The key factor in ice formation is heat loss from the water. Heat loss is mainly controlled by the *exposure* of the water to the atmosphere, and by the air temperature. The colder the air, the greater the heat loss, and the greater the rate of ice formation.

The matter of exposure needs some explanation. Water loses heat to air through three different physical processes: radiation, convection and conduction. Exposure really has to do with whether or not any barriers stand in the way of heat loss through these processes.

For example, a small stream in flat, open country, with very low banks and only grassy vegetation, has a very high exposure and is susceptible to ice formation (Fig. 4). First, nothing stands between the water and the sky, so radiation of heat to the sky is high. Second, the stream is open to the sweep of the wind, so convection in the air can easily take away the heat lost by the water. And third, in this open terrain the air near the stream is probably just about as cold as anywhere else, so conduction of heat to the air is high.

For comparison, picture a small stream in hilly or mountainous country, with high banks and very dense forest vegetation that overhangs the stream. Here the exposure is very

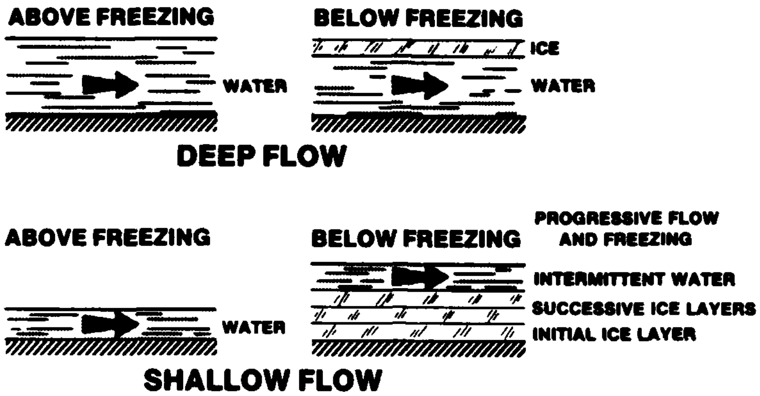


4. Examples of high and low stream exposure environments.

low. The overhanging vegetation shields much of the stream from the sky, so that heat loss by radiation is low. The dense forest protects the stream from the wind, holding down heat loss through convection. Finally, the air temperature in the forest may be higher than in the open, so heat conduction is less.

These two examples help us to visualize what is involved in heat loss from a water surface. But there is another factor besides heat loss that is important to consider in discussing ice-blocked drainage. That is *depth of flow*.

The depth of the flowing water, as compared to the thickness of the ice that forms for a particular amount of heat loss, is an important factor in ice-blockage problems (Fig. 5). If the depth of flow is much greater than the thickness of the ice, then ice blockage usually won't happen. It will happen when the depth of flow is about the same as or smaller than the thickness of the ice. Then the flow freezes solid, reducing the cross section of the culvert, drain, or ditch, and forcing subsequent flow to spread out on top of the ice and become frozen solid itself. This process of surface flow and freezing occurs over and over, and in extreme situations even a small flow can build up a tremendous amount of ice. For example, a flow of as little as 8 gallons per minute, if completely



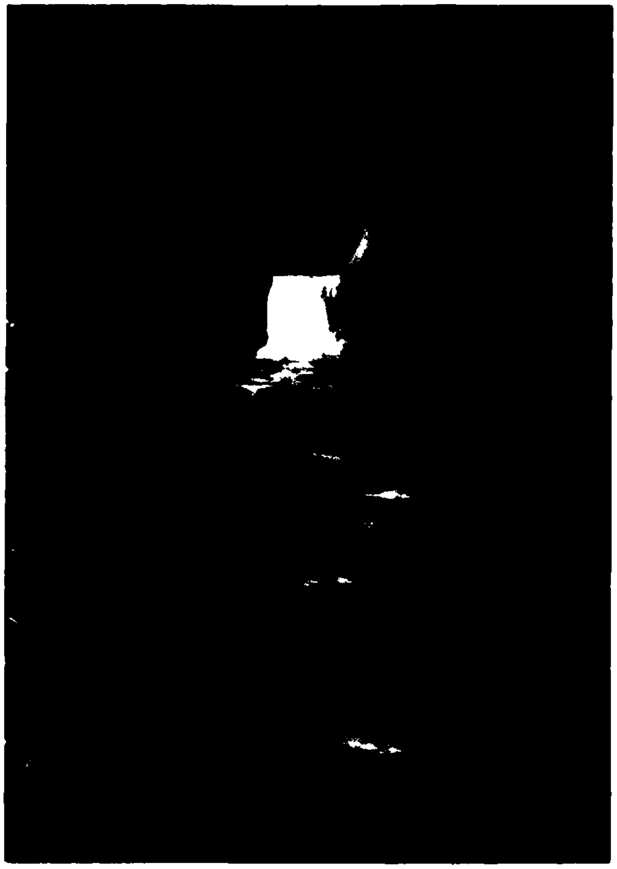
5. Freezing characteristics of deep and shallow flow. In the shallow flow situation the water depth is about equal to the ice thickness, while in deep flow it is much greater.

frozen, will cover an acre of land with more than a foot of ice in only a month.

With the above remarks about ice blockage in mind, we can look in detail at examples of particular ice-blockage processes.

Culverts. Probably the most frequent way that culverts are blocked by ice is by complete freezing, from water surface to bed, of the shallow flow at the bottom of the culvert. Both circular and pipe-arch metal culverts and box-type concrete culverts carry so little water in the winter that often the whole flow is frozen. Subsequent flow passes over the ice that's already there and becomes frozen solid in the same way. So the ice builds upward, layer by layer, and reduces the size of the culvert cross section. This is most likely to happen at one or both ends of the culvert, where the exposure is greatest. In the middle of the culvert the exposure is less, and also the temperature is usually higher because the culvert is surrounded by the embankment material, which is usually much warmer than the air. Thus it's less common for complete freezing to happen in the middle. But if the culvert is large in diameter, or, particularly, in a windy location, the slightly warmer conditions in the middle of the culvert are eliminated, and the water will freeze there too.

Another very common place for a culvert to become blocked is at an end designed for free-fall of the outflow (Fig. 6). The pipe extends out from the embankment above the toe of the slope. This means that the outside of the culvert is exposed to cold air around its entire circumference, so the flow along the bottom of the culvert is chilled from both above and below. Quick freezing and blockage can result.



6. Free-fall culvert outlet in the early stages of ice formation. Continued flow and freezing will block it.

Other culvert situations that cause ice problems are debris and splashing. Debris is cold, and ice crystals in the flow can stick to it, blocking the small openings the water would otherwise flow through. Poor culvert shapes, poor inlet and outlet conditions, and other causes can lead to splashing of the flow. When splashing water falls on the cold surface of the culvert material, it quickly freezes and ice builds up in thin layers. Given enough time, this can hamper the flow and even block it completely.

Ditches. Just as in culverts, the most common way that ditches become blocked is by complete freezing of shallow flows at the bottom, followed by repeated flow and freezing, until ice builds up to the top of the ditch. Or, when the ditch is at the base of a cut slope, seepage from the slope may

7. Water seepage down the face of this cut slope in rock has frozen and completely filled the ditch between the cut face and the road.

freeze as it runs down to the ditch. Successive freezing of this sort builds up ice on the side and bottom of the ditch, and can block it (Fig. 7).

Snow can lead to ice blockage in ditches in two ways. First, falling and drifting snow that fills the ditch will tend to block water flow. Plowed snow is especially apt to form a dam, since it is compacted. If the ditch is shallow or the depth of snow is small, the saturated snow can freeze easily. (Deeper ditches or deeper snow covers result in the opposite effect, because the snow insulates the unfrozen water at the bottom of the ditch.) Second, in the early spring when snow and snowbanks are melting during the day, melt water runs to the ditches. When night comes this flow freezes. Eventually, as the spring progresses, daytime melting of snow becomes greater than the nighttime freezing of runoff. But early in the season, the freezing is greater than the melting, so that at the very time when drainage facilities are needed most, they are being filled with ice.

Subsurface Drains. The outflow from subsurface drains, particularly in winter when there is little if any inflow, is seldom more than a trickle. It is very easy for this outflow to

freeze at the points where it emerges, because the exposure is high and the depth of flow is small. Since the temperature in subsurface drainage systems is usually above freezing, water will continue to flow to outlets and freeze there. When the outlets freeze completely, water backs up and the system stops operating. The groundwater level rises and the soils that were meant to be drained become saturated.

Additional information

Two CRREL publications that may be useful as sources of additional information are listed below. These reports apply to severe icing problems found in very cold climates, but the ideas they contain are applicable to the general problems of ice-blocked drainage facilities.

Carey, K.L. (1970) Icing occurrence, control and prevention: An annotated bibliography. USA Cold Regions Research and Engineering Laboratory, Special Report 151. AD711534.

Carey, K.L. (1973) Icings developed from surface water and ground water. USA Cold Regions Research and Engineering Laboratory, Cold Regions Science and Engineering Monograph III-D3. AD765452.

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